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BEHAVIOR OF METAL MATRIX COMPOSITES AT CRYOGENIC TEMPERATURES

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FOR NAVAL SURFACE WARFARE CENTER
RESEARCH AND TECHNOLOGY DEPARTMENT

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A cryogenic mechanical testing facility was constructed capable of testing materials from 4.2 degrees Kelvin to room temperature. Three tensile tests were performed on P55 Gr/6061 Al metal matrix composites. At 4.2 degrees Kelvin, the elastic modulus was 21.7 million psi and the ultimate tensile strength was 85.1 jsu, At 77 degrees Kelvin, the elastic modulus was 20.5 million psi , and the ultimate tensile strength was 78.4 ksi. At 293 degrees Kelvin, the elastic modulus was 27.4 million psi, and the ultimate tensile strength was 93 ksi.

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FOREWORD

This work was performed for and funded by the Naval Surface Weapons Center SBIR Program, Topic Number N86-112. Thc results and conclusions presented in this report concern the tensile behavior of metal matrix composites from room temperature to liquid helium temperatures. Three graphite/aluminum composite tests were done to prove the capability of performing future tests. The temperature of the tests were at 293K, 77K, and 4.2K. Both ultimate tensile strength and elastic modulus measurements were obtained.

The P55 Gr/6061 Al composite material used for testing was provided by John Foltz at NSWC, who monitored the contract.

Approved by:

C. E. Mueller

C. E. MUELLER, Head
Materials Division

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SECTION 1

INTRODUCTION

PROBLEM STATEMENT

The requested exploratory development stated in the SBIR solicitation N86-112 was:

"(Reference 1) Metal matrix composites are candidates for use as structural materials on satellites and spacecraft. The task is to develop a data base reflecting thermomechanical characteristics of these composites at very low temperatures typical of orbital and deep space conditions. "

SIGNIFICANCE OF THE PROBLEM

Uses

Metal matrix composites (MMC) are valuable structural materials for spacecraft and have been used for mirror substrates, support booms, antenna ribs, wave guides, and heat exchangers according to Wolff (Reference 2) and Zweben (Reference 3). The advantages of MMCs are:

(1) High strength to weight ratio.

(2) High stiffness.

(3) Low coefficient of thermal expansion in the longitudinal direction of the fibers.

Fabrication Methods

Matrix materials are typically aluminum and magnesium. Carbon filaments with a diameter of 10 microns (micrometers) are typical and form continuous fibers within the metal matrix. The most common method used in making the fibers is to pass graphite yarn through a furnace, and deposit a titanium-boron coating by chemical vapor deposition, which promotes wetting. This coated yarn then passes through a bath of molten aluminum or magnesium producing an infiltered bundle of fibers, Reference 3, which is known as a "wire." Many wires are interleaved between foils of aluminum or magnesium and hot rolled or diffusion bonded which forms the MMC.

Performance Limitations

Unfortunately, the coefficient of thermal expansion of the matrix material such as aluminum is 13.1 microinches/inch deg. F while that of the graphite is typically - 0.6 microinches/inch degrees F. The thermal expansion coefficient of the composite is between 0.6 and 0.9 microinches/inch degrees F according to Dries and Tompkins, Reference 4. This means that the aluminum matrix is under tension while the fibers are in compression at room temperature. As the temperature is lowered, the stress differentials increase. The result is plastic deformation of the aluminum which creates open hysteresis loops initially in unstabilized MMCs. Even MMCs that have undergone many temperature cycles, still may exhibit hysteresis loops. Since the temperatures experienced by spacecraft can go down to a few degrees above absolute zero in deep space, the MMCs will have to withstand these temperatures. Estimates of temperatures were made for temperatures experienced at Saturn of 84.4 degrees K down to 42.7 degrees K at Pluto for direct black body absorption due to the solar constant, References 1 and 5. For that portion of the space vehicle not directly absorbing solar energy, temperatures are even lower. Therefore, it is important to determine the structural properties of MMCs at low temperatures.

Technical Objectives

The purpose of the present work was to develop a capability of testing and evaluating the thermal mechanical properties of MMCs ranging from room temperature down to liquid helium temperatures (4.2 degrees Kelvin). This would involve:

(1) Construction of a cryogenic mechanical testing machine.

(2) Building a tensile testing fixture.

(3) Building a compression testing fixture.

(4) Development of the capability to examine test specimens that have undergone mechanical tests.

(5) Providing at least one tensile test at 77 degrees K and 4.2 degrees K of a MMC to demonstrate the capability of performing these type of tests.

SECTION 2

CRYOGENIC MECHANICAL TESTING EQUIPMENT

TENSION TESTING CRYOGENIC APPARATUS

Testing Machine

A Sintech CITS 2000-6 computer integrated testing system capable of mechanically testing with forces up to 6,000 pounds and a cross-head speed range of 0.02 mm/min to 500 mm/min. was purchase. This machine is controlled by an IBM Personal Computer which controls the cross-head movement and analyzes the test data.

Tension Testing Cryogenic Apparatus

Figure 1 shows a schematic drawing of the tension testing cryogenic apparatus that fits onto the Sintech testing machine. The upper beam of the testing frame is supported by two tension posts that are attached to a lower beam of the testing frame. The lower beam is in turn mounted onto the bottom frame of the Sintech testing machine. At the top central portion of the testing frame a compression tube is fixed via a compression cylindrical housing. At the bottom of the compression tube hangs a tension fixture to which is attached the bottom grips that hold a tensile specimen. The purpose of this entire assembly, which remains essentially fixed during testing, is to provide a downward force upon the specimen during testing. The compression tube with its baffles fits into a cryostat capable of achieving low temperatures. One can see this arrangement by the overlay of Figure 1 on Figure 2 which is the cryostat.

The cross-head of the Sintech testing machine moves up and down. At the bottom of the cross-head is attached a load cell which electronically measures the force exerted upon the specimen during testing. Below the load cell hangs a universal joint and then the tension rod. The purpose of the universal joint is to provide an axial force on the specimen. At the bottom end of the tension rod is attached the top grip which holds the upper portion of the specimen.

Both the compression tube and tension rod are made of Inconel 600 because of the low thermal conductivity of this material, 3 milliwatts/cm. deg. K according to Scott, Reference 6. At the same time, the 0.2% yield strength of this alloy is 92.3 ksi. These characteristics plus the carefully designed copper baffles which utilize the enthalpy of the evaporating liquid helium minimize the loss of liquid helium. Measure- ments made during a liquid helium run have given a liquid helium loss rate of 60 ml/hour for the cryostat and tension testing cryogenic apparatus combined. This apparatus is capable of producing a force of up to 5,000 pounds.

CRYOSTAT

A Janis 10CNDT, Serial No. 3963, was specially designed to fit within the dimensional constraints of the tensile testing machine. Figure 2 shows this cryostat. This cryostat was built with a liquid helium valve which connects to a vaporizer assembly via a capillary tube. This feature allows the cryostat to be a variable temperature cryostat capable of obtaining temperatures between 2 K and 300 K. A silicon diode thermometer is also attached at the vaporizer assembly. This capability was proposed for Phase II, Reference 1, but it was installed for an eventual cost savings should Phase II be awarded. The bottom portion of the cryostat liquid helium chamber had a bevel so that liquid nitrogen could be used to precool the contents within the central test chamber and then removed with a tube prior to a liquid helium transfer. A thermal anchor was provided between the liquid nitrogen chamber and the central test chamber so that there could be conduction of heat from the compression tube, Figure 1, via the top baffle. This arrangement reduces the heat conduction to the tension fixture. The top laddish (cover) on the cryostat test chamber actually has a hole with an "O" ring. Within this hole slides the compression cylindrical housing to which is attached the compression tube, see Figure 1. The purpose of this arrangement is so that the chambers of the cryostat can be evacuated. Also, no appreciable force, shock or otherwise, can be transferred to the cryostat during testing and breakage of the specimen. This same philosophy was used with the three supporting screws which go through the dewar mounting flange. These screws fit into three brass cylinders fixed to an aluminum platform attached to the bottom of the Sintech tensile testing machine. The lower beam of the testing frame, Figure 1, is isolated from the aluminum platform via a felt washer. Thus a downward deflection of the lower beam upon breakage of the specimen will not transmit a shock force onto the cryostat.

CONTROL AND RECORDING APPARATUS

Pumping Equipment

A Varian SD-200 rotary vacuum pump with a 7-cfm free air displacement and an ultimate vacuum of 10 torr is used to rough out the helium and test chambers. Also it was used for preliminary evacuation of the vacuum chamber of the cryostat. Final evacuation of that chamber was accomplished by a

Varian 8 liter per second Vacion pump. An oil mist eliminator and oil trap were installed to keep oil vapors from contaminating the cryostat and entering the room. A Vacion controller, bottom right corner of Figure 3, was used to control the Vacion pump and to measure the ultimate pumping pressure of about 10 torr in the cryostat vacuum chamber. A thermocouple gauge was used for pressures between 2 torr and 10 torr, see Figure 3. A Wallace and Tiernan pressure gauge was used for pressure measurements between 760 and 1 torr. There were also vacuum valves and flow valves to select and control the evacuation and purging of the various chambers within the cryostat. A gas flow meter, to the left of the Wallace and Tiernan pressure gauge, was used to measure the liquid helium evaporation rate.

Mechanical Testing and Control Equipment

Figure 3 shows the IBM PC used to control the Sintech testing machine. Results of the tests were visible on the monitor, and these were printed out on an Epson LQ-800 printer. Plots of the load-elongation curve could also be made on the Hewlett-Packard Color Pro plotter.

Temperature Measurement and Liquid Helium Level Measurement

A silicon diode was placed on top of the bottom baffle of the tension testing cryogenic apparatus, Figure 1. A 10-milliamp current was supplied to the diode and the voltage measured with a digital voltmeter. Temperature could be determined by the diode voltage thus measured, which was the temperature above the tension fixture. A split copper container surrounded the tension fixture which ensured the isothermal condition of the contents within the container. The liquid helium level within the liquid helium chamber of the cryostat was measured by an American Magnetics Model 110A helium level gauge.

OPERATING CONDITIONS OF CRYOGENIC MECHANICAL TESTING EQUIPMENT

Cryostat With Tensile Testing Apparatus Fully Assembled

Figure 4 shows the cryostat with the tension fixture, compression tube, and tension rod fully assembled within the testing chamber of the cryostat. The evacuation tube are in place. The top beam is attached to the tension posts on either side of the cryostat by means of two knurled nuts.

Cryostat With Tensile Testing Apparatus Partially Withdrawn

Figure 5 shows the cryostat with the compression tube and tension rod partly withdrawn out of the testing chamber of the cryostat. This is accomplished by unscrewing the knurled nuts holding the top beam onto the tension posts and attaching two brass knurled screws through the top beam onto a plate at the bottom end of the cross-head of the Sintech machine. As the cross-head moves upward, it will then carry the compression tube and tension rod with tension fixture upward.

Cryostat with Tensile Testing Apparatus Completely Withdrawn

Figure 6 shows the cross-head at its uppermost condition. Here, one can see the split copper can surrounding the tension fixture. When the can is removed, one might obtain access to the specimen.

Tension Fixture with Fractured Graphite/aluminum Composite

Figure 7, shows a P55 Gr/6061 Al tension specimen that had been fractured in a room temperature test. One can see a strain gauge made by John A. Shepic attached to the test specimen. This strain gauge was calibrated and is accurate to better than 0.2 percent of its full range of 0.015 inches or 1 percent of its displacement, whichever is the smaller value. The calibration value of the gauge at room temperature was 1.387 + or - 0.002 when used with the Sintech testing machine. These values should not change significantly at 77 degrees K or 4.2 degrees K according to John A. Shepic, Reference 7, although calibration was not done at those temperatures by this author up to the present time. The Si diode thermometer can also be seen held down by a clamp that is attached to the top of the bottom baffle just above the tension fixture.

Compression Fixture Attached to Cryogenic Testing Apparatus

Figure 8 shows this fixture. The top and second to the bottom brass disks remain stationary, the top disk being attached to the compression tube. The second to the top and the bottom brass disks move up and down. The second to the top disk is attached to the tension rod via a hemispherical screw. Compression platens are mounted between the bottom and second to the bottom [illegible]. Stainless steel rods that attach pairs of disks and slide between the [illegible]r pairs can also be seen in the figure.

SECTION 3

TEST RESULTS

TEST SPECIMEN CONSTRUCTION

Figure 9 shows a 55P Gr/6061 Al tensile testing bar 3.5 inches long, far left. Next to the bar to the right is a titanium tab. The tab is one inch long with a 5-degree taper. The reason for selecting titanium is that its coefficient of thermal expansion (CTE) is low, approximately 5 microinches/ inch degree F. Since the CTE of aluminum is 13.1 microinches /inch deg. F and that of the Gr/Al MMC is only 0.8 microinches/inch deg. F, it was believed that the selection of titanium would provide less thermal stress on the specimen when subjected to low temperature tests. The use of titanium or tungsten was suggested by Kent Busking, Reference 6, for this reason. Pairs of tabs were epoxied on either end of the tension bar using a Miller-Stephenson epoxy 907 with a tensile shear strength of 3300 psi at 75 degrees F and 2500 psi at 67 degrees F. It was discovered that the tabs were so hard that they slipped in the grips during testing. As a result, aluminum tabs were epoxied onto the titanium tabs, see the rightmost specimen in Figure 9. The aluminum was sufficiently soft to permit imbedding the grip jaw serrations, thus eliminating the slip problem.

SPECIMENS AFTER TENSILE TESTING

Figure 10 shows three specimens after tensile testing. The one tested at room temperature shows fracture of the specimen at the tip of the titanium tabs. One can clearly see the graphite fibers. The bottom half of the specimen with tabs is turned 90 degrees for a side view of the fracture.

The specimen that broke at 77 degrees K broke part of the way within the tabs, but outside of the clamped region of the jaws. It is therefore believed that the breaking strength is close to that of the true MMC ultimate tensile strength.

The specimen that broke at 4.2 degrees K broke in a similar manner, part way between the end of the tabs and the jaws of the grips. The breaking strength as measured is again probably close to the true ultimate tensile strength of the MMC.

ROOM TEMPERATURE TENSILE TEST

A tensile test at 293 degrees K was performed, see Figure 11. The elongation was measured using the strain gauge extensometer previously described. Young's modulus was measured between the letters (b) and (m) in the figure. Test results are also shown in Table 1. Here, the ultimate tensile strength was 93 ksi and the elastic modulus was 27.4 million psi. The yield stress, indicated by (y) on the load elongation curve is probably not yielding of the MMC, but rather the fracture of graphite fibers within the gauge length of the specimen prior to the final fracture which is at a peak load of 1,090 pounds. Figure 11 was done on the Epson LQ-800 printer.

LIQUID NITROGEN (77 DEGREES K) TENSILE TEST

Figure 12 and Table 2 present the results of tensile testing a MMC of type P55 Gr/ 6061 Al at 77 degrees Kelvin. The elastic modulus is again shown between the letters (b) and (m). Above point (m), the load elongation curve moves to the left, showing a relaxation of strain between the clamping screws spanned by the extensometer. The reason for this is that probably some graphite fibers broke in a region outside of the gauge length. The load was taken up by the fibers that remained intact and an increase in load was then sustained by these fibers. A similar discontinuity occurred at about 650 pound load. Although the ultimate breaking stress was calculated to be 78.4 ksi, it is not clear that the true breaking stress is that low. It might well be as high as the room temperature value were it not for the fractured fibers during earlier parts of the test. Young's modulus, on the other hand, is probably correct at 20.5 million psi. It is interesting to note the drop in stiffness of this MMC from room temperature, which confirms a report from Foltz, Reference 8.

LIQUID HELIUM (4.2 DEGREES K) TENSILE TEST

A tensile test was performed on an MMC of type P55 Gr / 6061 Al, the results of which are shown in Figure 13 and Table 3. Young's modulus was determined between the letters (b) and (m) and is 21.7 million psi. At 390 pounds load, the load elongation curve veers to the left indicating fracture of graphite fibers in a region outside of the gauge length. However, as the load increased, the load elongation curve moved to the right more rapidly than indicated by true elastic deformation, probably due to fracture of graphite fibers within the gauge length. This occurred up to a load of about 790 pounds. Then the load elongation pattern followed the elastic line up to the breaking point at a load of 960 pounds, where the MMC broke. Here the ultimate tensile strength was calculated to be 85.1 ksi which is probably lower than the true breaking strength of the MMC.

ERROR DUE TO FRICTION BETWEEN "O" RING AND TENSION ROD

Figure 14 shows a load elongation curve due to movement of the cross-head without a specimen between the grips. Friction gives fluctuations in load of + or - 0.3 pound with an occasional load spike of one pound. Thus, the error introduced in the above tests is a fraction of one percent. The plot of this figure was done with the Hewlett-Packard Color Pro plotter.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the elastic modulus decreases from 27 million psi at room temperature to around 21 million psi at liquid nitrogen temperature (77 degrees K) and then stabilizes at that value down to liquid helium temperatures (4 degrees K). The breaking strength is probably slightly above 93 ksi at room temperature and would remain constant as the temperature drops to 4 degrees K if graphite fibers did not break during the tensile test. This fracturing probably occurs due to uneven load distributions on the fibers resulting from localized yielding of the aluminum matrix. This yielding of the matrix is most likely due to large residual tensile stresses resulting from thermal expansion differences between the aluminum matrix and the graphite fibers. As a result, the apparent ultimate breaking strength decreases to about 78 ksi 77 degrees K and 85 ksi at 4.2 degrees K.

Since space vehicles are also subjected to localized stress concentrations due to thermal expansion differences between the metal matrix and the graphite fibers, it would be safer to use the measured ultimate breaking strength for design purposes. The experiments in this report are intended to demonstrate the proper working of the cryogenic mechanical testing equipment and are of insufficient quantity to draw firm conclusions. The primary conclusion is that the equipment works properly. It is recommended that a much more extensive experimental effort be expended in gathering mechanical testing data for currently used MMCs such as type P 100 Gr/6061 Al and similar graphite/magnesium MMCs.

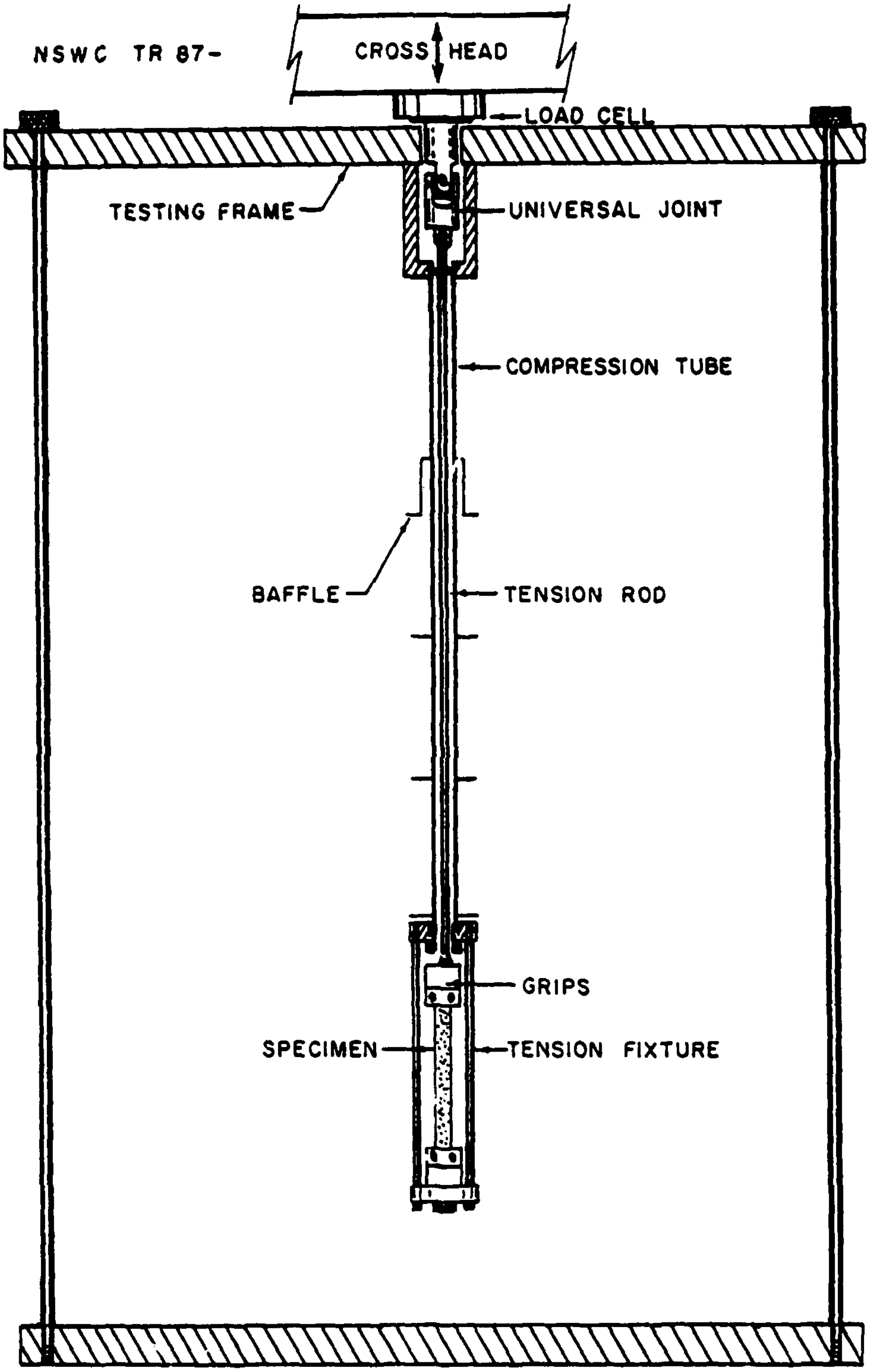

FIGURE 1. TENSION TESTING CRYOGENIC APPARATUS

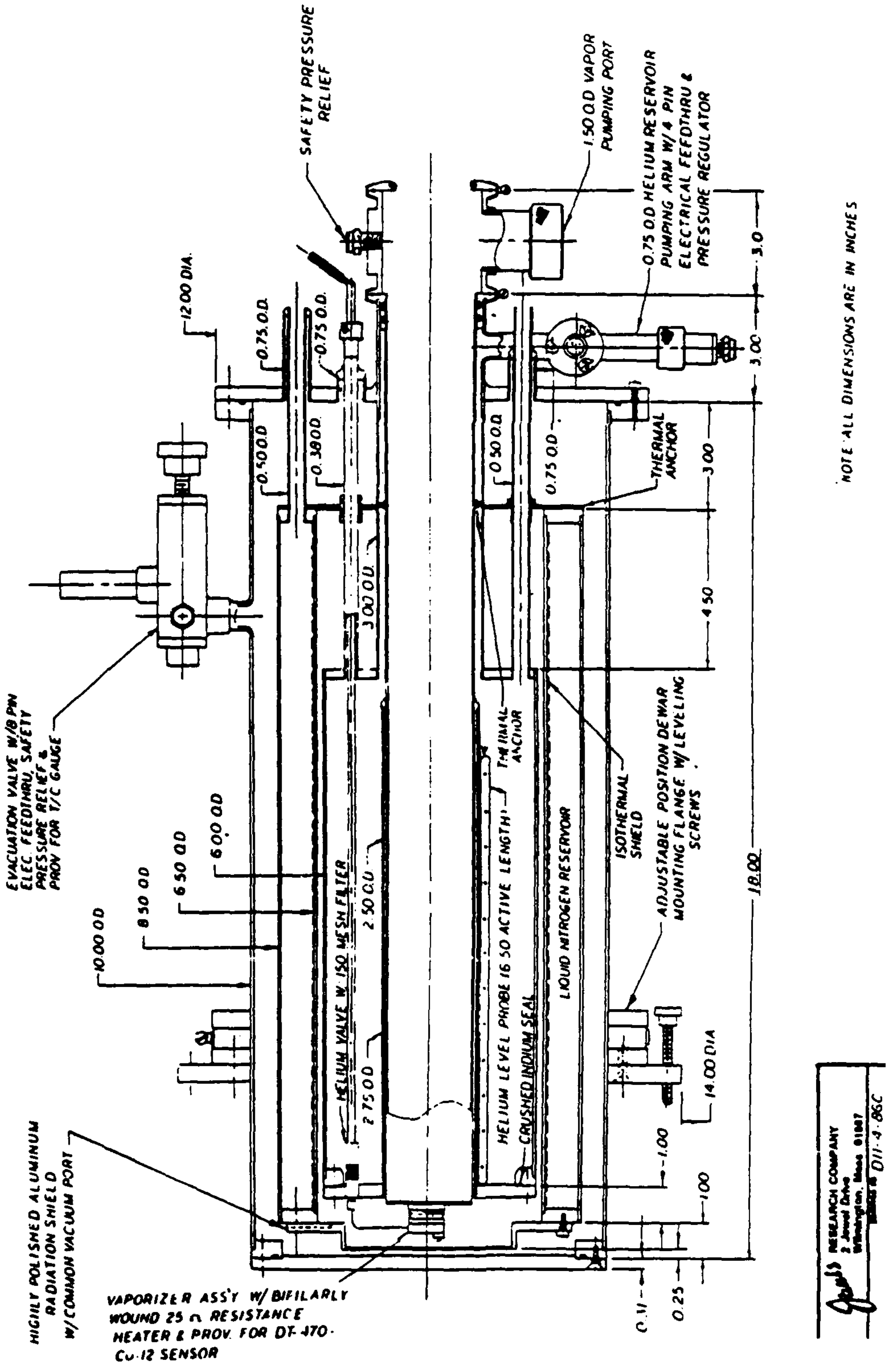

FIGURE 2. SPECIAL 10 CNDT "SVT" CRYOSTAT

FIGURE 3. CONTROL AND RECORDING APPARATUS FOR TENSILE TESTING AT TEMPERATURES FROM 4K TO 300K. THESE ARE AN EPSON LQ- PRINTER, HEWLETT PACKARD COLOR PRO PLOTTER, IBM PC, WALLACE & TIERNAN PRESSURE GAUGE, VALVES AND THERMOCOUPLE GAUGE, VACION PUMP CONTROLLER, LIQUID HELIUM LEVEL GAUGE, AND LAKE SHORE CRYOTRONICS 110 CURRENT SOURCE FOR Si DIODE

FIGURE 4. CRYOSTAT WITH TENSILE TESTING APPARATUS FULLY ASSEMBLED WITH SINTECH TENSILE TESTING MACHINE

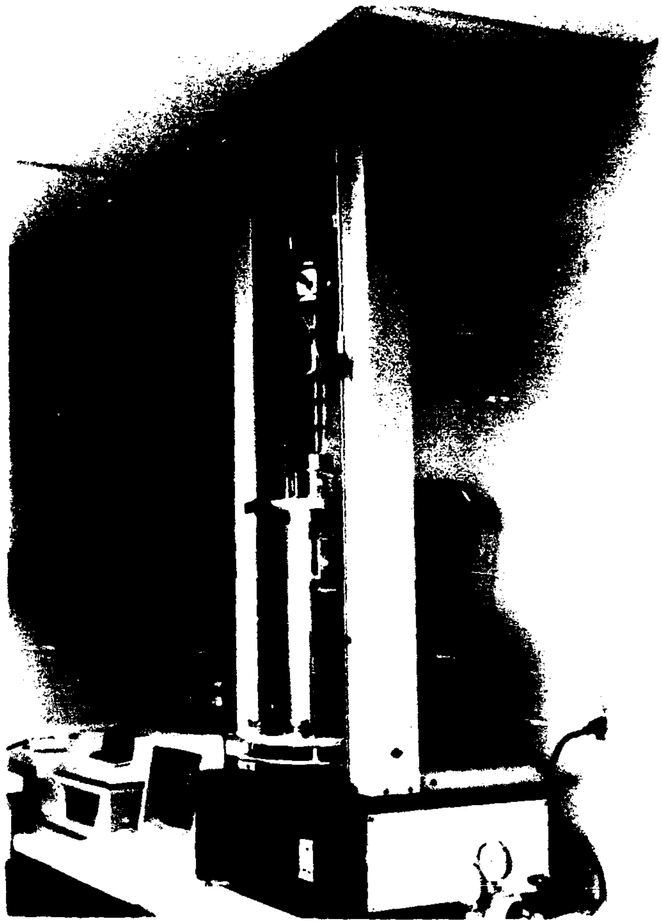

FIGURE 5. CRYOSTAT WITH TENSILE TESTING APPARATUS PARTIALLY WITHDRAWN FROM JANIS CRYOSTAT BY CROSS-HEAD OF SINTECH TESTING MACHINE

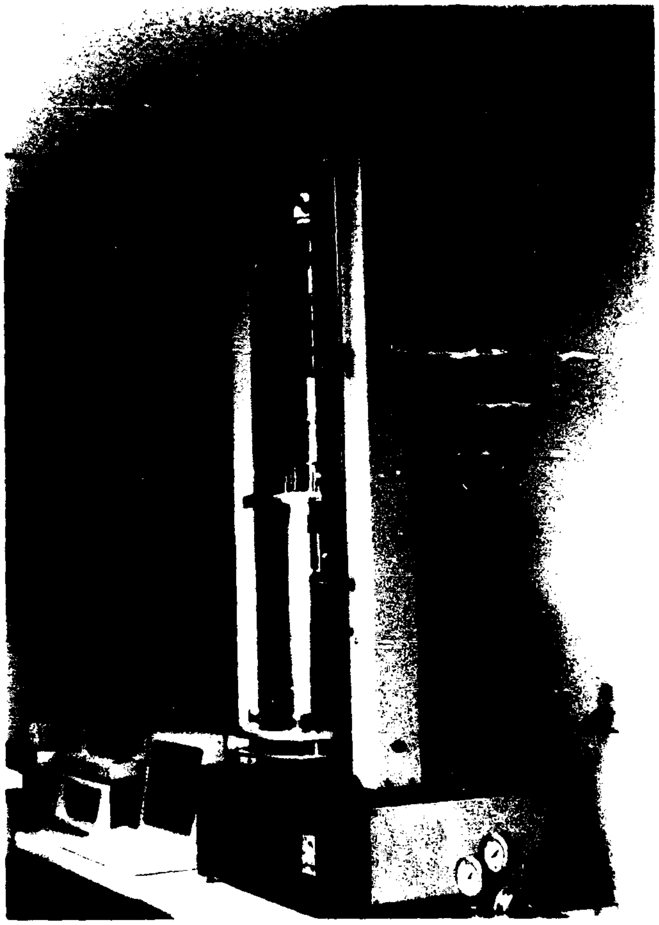

FIGURE 6. CRYOSTAT WITH TENSILE TESTING APPARATUS COMPLETELY WITHDRAWN FROM JANIS CRYOSTAT BY CROSS-HEAD OF SINTECH TESTING MACHINE

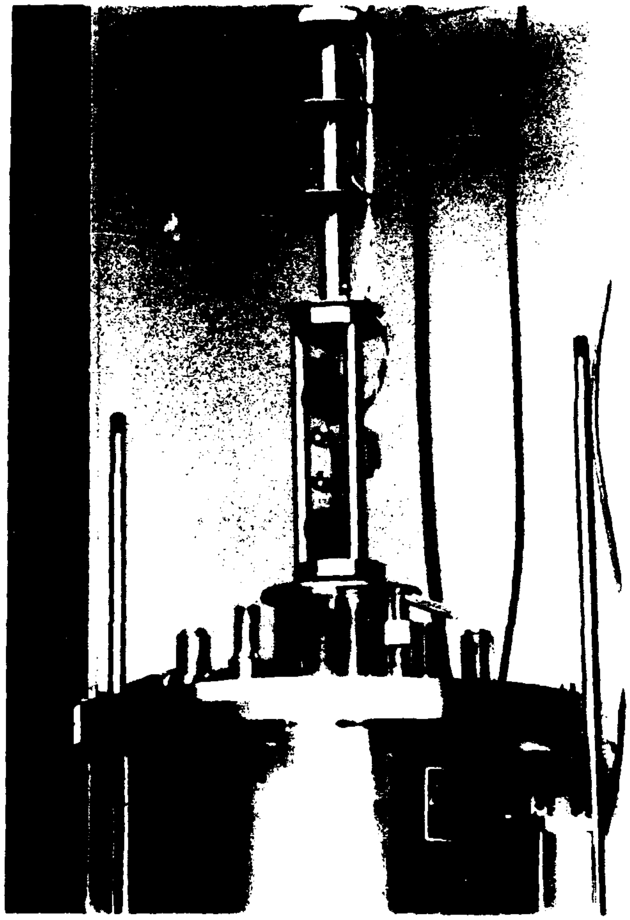

FIGURE 7. TENSION FIXTURE WITH FRACTURED GRAPHITE/ALUMINUM COMPOSITE, P55 FROM PANEL NO. G5123. STRAIN GAUGE EXTENSOMETER ATTACHED

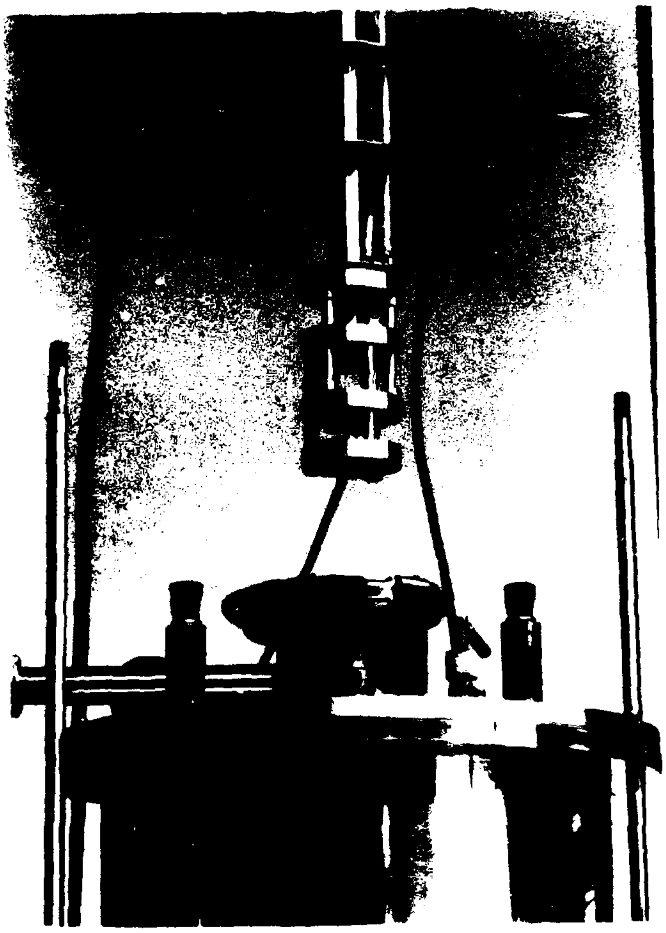

FIGURE 8. COMPRESSION FIXTURE ATTACHED TO CRYOGENIC TESTING APPARATUS

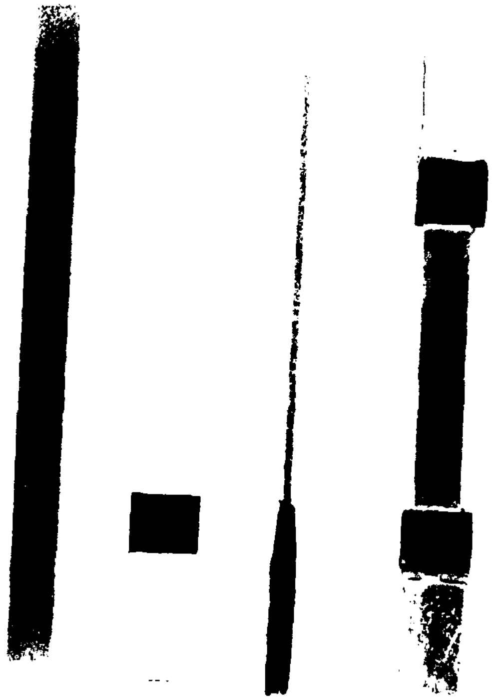

FIGURE 9. TENSILE TESTING SPECIMENS, FROM LEFT TO RIGHT: ALUMINUM/GRAPHITE COMPOSITE BAR, TITANIUM TAB, COMPOSITE BAR WITH TWO MOUNTED TITANIUM TABS, COMPLETELY ASSEMBLED COMPOSITE BAR WITH EPOXIED TITANIUM AND ALUMINUM TABS - MAGNIFICATION 1 x

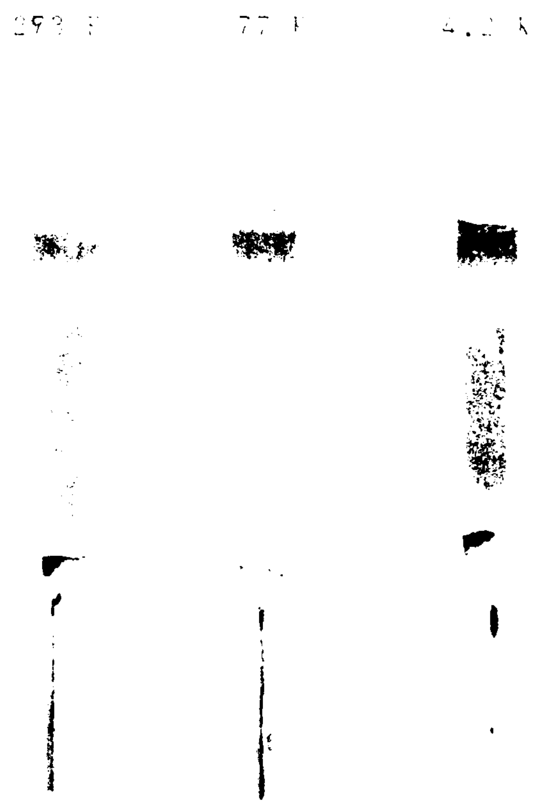

FIGURE 10. TENSILE TESTING SPECIMENS OF ALUMINUM/GRAPHITE P 55 COMPOSITE FROM PANEL G5123 TESTED AT THREE TEMPERATURES - MAGNIFIED 1 x

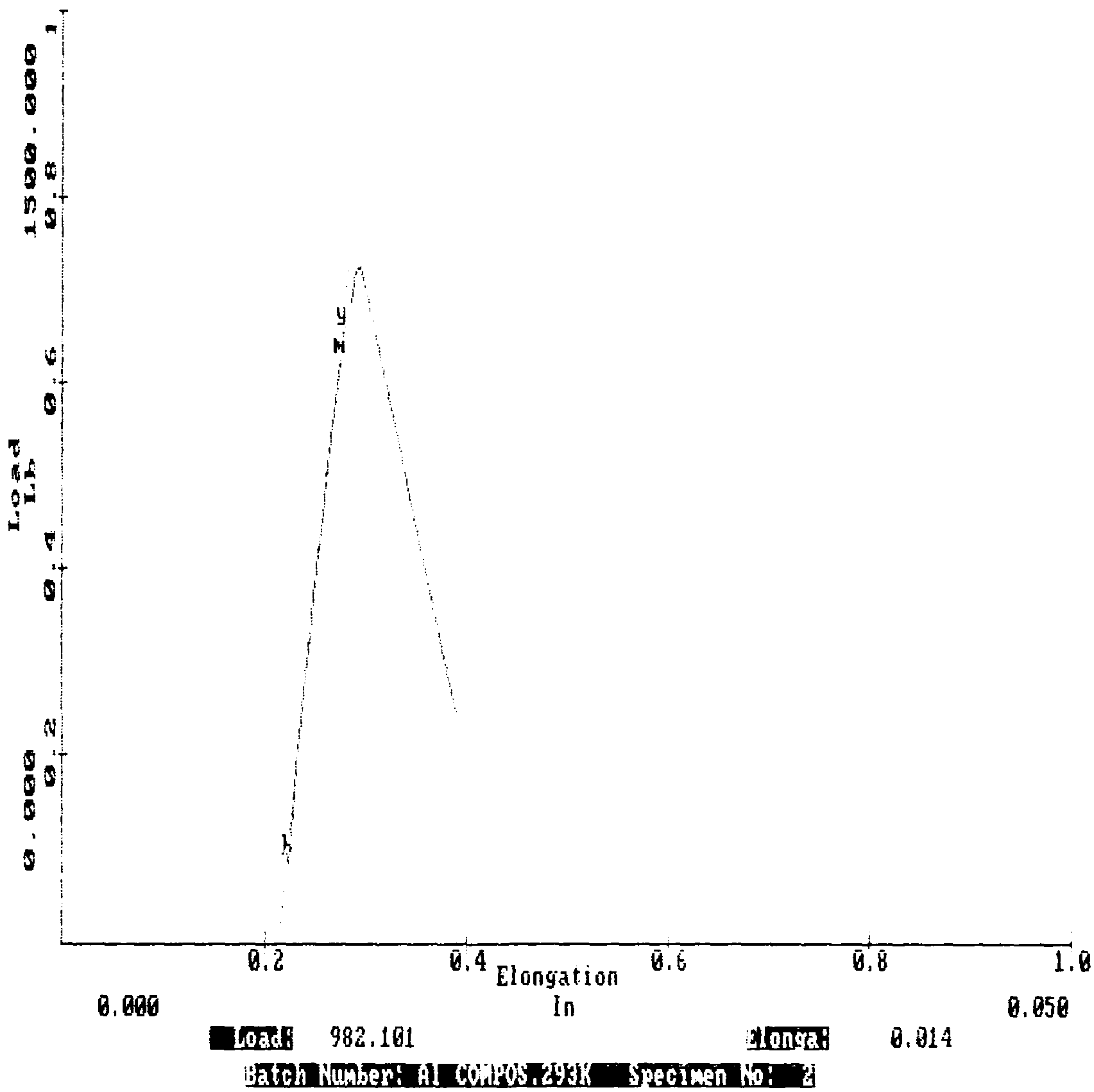

FIGURE 11. ALUMINUM/GRAPHITE P55 COMPOSITE TENSILE TESTED AT 293K

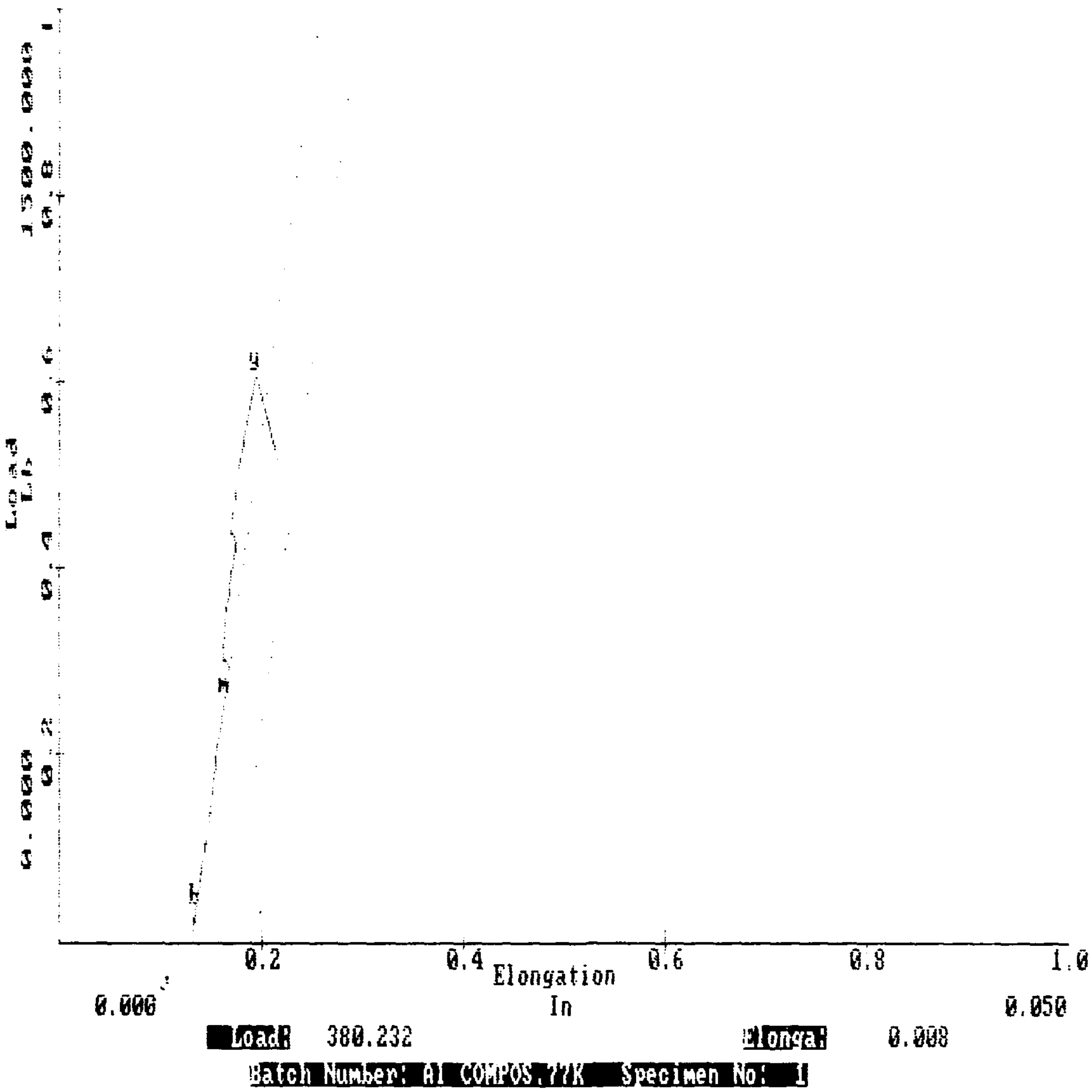

FIGURE 12. ALUMINUM/GRAPHITE P55 COMPOSITE TENSILE TESTED AT 77 K

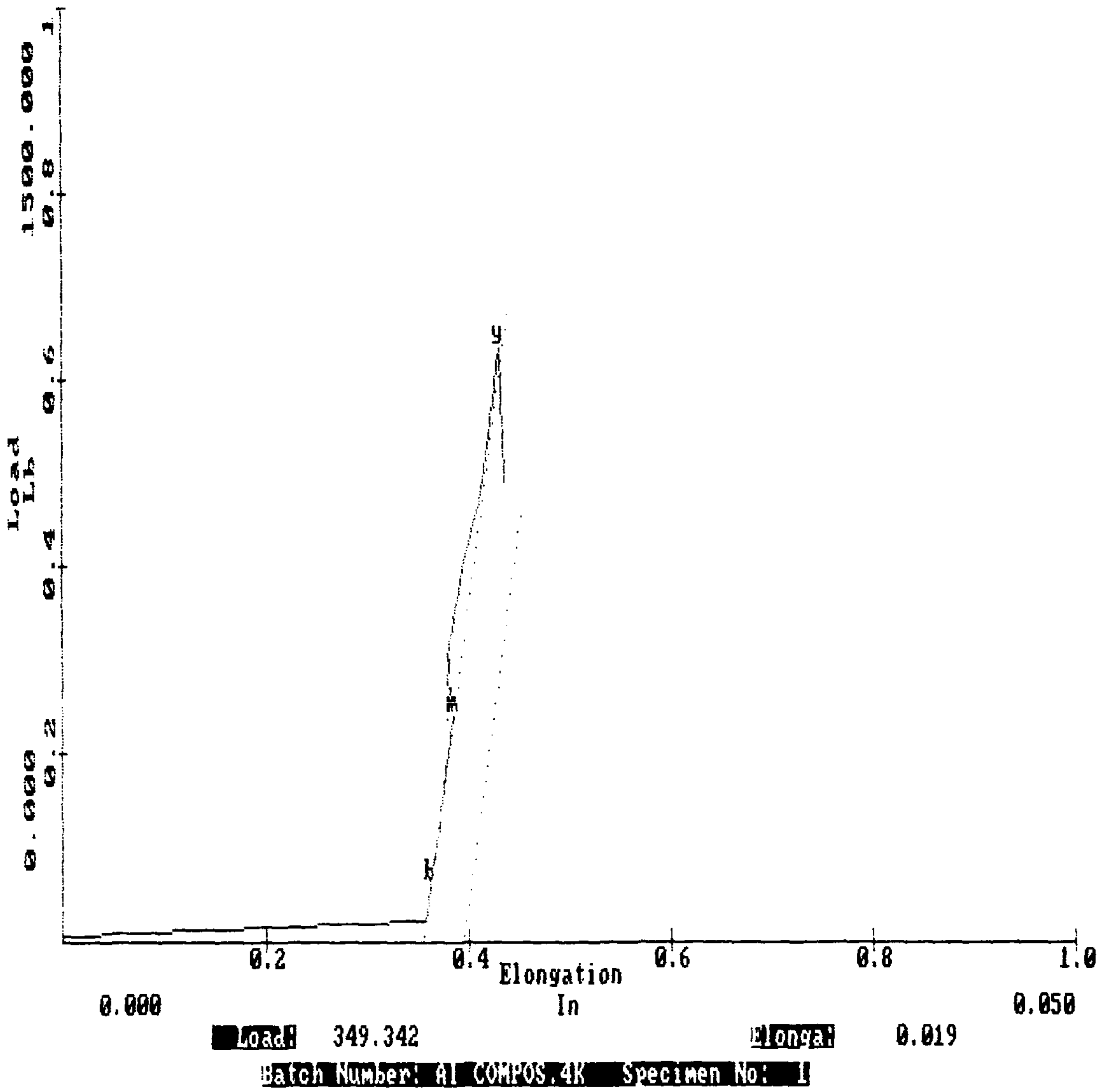

FIGURE 13. ALUMINUM/GRAPHITE P55 COMPOSITE TENSILE TESTED AT 4.2K

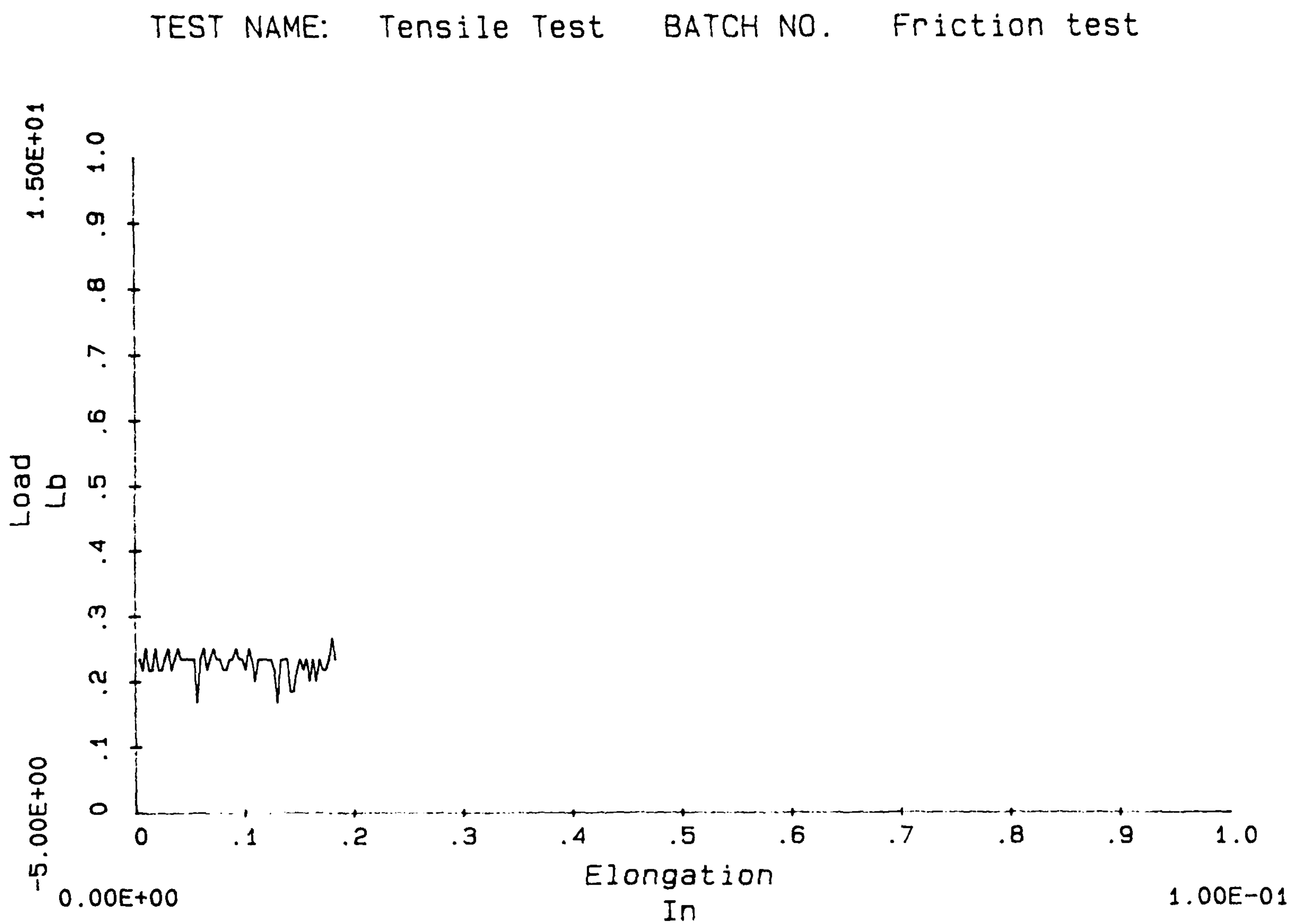

FIGURE 14. TENSION TESTING CRYOGENIC APPARATUS FRICTION TEST

TABLE 1. ALUMINUM/GRAPHITE P55 COMPOSITE TENSILE TESTED AT 293K

ADVANCED MATLS. LAB

Concord, MA

Tensile Test

Batch Number: Al COMPOS.293K
Date: 04-03-87

Number of Specimens : 1

Operator I.D. :............... TA
Storage Disk No. :............ 1
Comments :.................... A16061+ C P55 #G5123

TEST RESULTS

	Thick./Dia In	Width In	Peak Load Lb	U.T.Stngth PSI	Yld Stngth PSI	Yld Elong. %	Brk Stngth PSI	Brk Elong. %	Modulus PSI	Energy Ft-Lb
1	0.047	0.250	108.628E+01	930.436E+02	794.593E+02	0.295	930.436E+02	0.400	273.702E+05	0.488

STATISTICS

Mean	0.047	0.250	108.628E+01	930.436E+02	794.593E+02	0.295	930.436E+02	0.400	273.702E+05	0.488
Min	0.047	0.250	108.628E+01	930.436E+02	794.593E+02	0.295	930.436E+02	0.400	273.702E+05	0.488
Max	0.047	0.250	108.628E+01	930.436E+02	794.593E+02	0.295	930.436E+02	0.400	273.702E+05	0.488
St.Dev	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% C.V.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TEST CONDITIONS

Crosshead Speed :............. 0.1 In/Min
Load Cell Capacity :.......... 5000 Lb
Threshold :.................. 5 % Of FSL
Break Criterion :............. 95 %
Extensometer Used :........... 1 1:Y,0:N
Gage Length :................. 1.00 In
Action @ End Of Test :........ 1 1:St,0:Rtn
Crosshead Direction :......... 1 1:Up,0:Dn
Yield(Zero,Offset) :.......... 2.0 1:Z,2:Off
Offset At Yield :............. 0.2 %

TABLE 2. ALUMINUM/GRAPHITE P55 COMPOSITE TENSILE TESTED AT 77K

ADVANCED MATLS. LAB

Concord, MA

Tensile Test

Batch Number: Al COMPOS.77K
Date: 04-05-87

Number of Specimens : 1

Operator I.D. :............... TA
Storage Disk No. :............ 1
Comments :.................... Al6061+ C P55 #G5123

TEST RESULTS

	Thick./Dia In	Width In	Peak Load Lb	U.T.Stngth PSI	Yld Stngth PSI	Yld Elong. %	Brk Stngth PSI	Brk Elong. %	Modulus PSI	Energy Ft-Lb
1	0.046	0.250	903.135	783.502E+02	658.579E+02	0.428	783.502E+02	0.314	205.402E+05	0.197

STATISTICS

Mean	0.046	0.250	903.135	783.502E+02	658.579E+02	0.428	783.502E+02	0.314	205.402E+05	0.197
Min	0.046	0.250	903.135	783.502E+02	658.579E+02	0.428	783.502E+02	0.314	205.402E+05	0.197
Max	0.046	0.250	903.135	783.502E+02	658.579E+02	0.428	783.502E+02	0.314	205.402E+05	0.197
St.Dev	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% C.V.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TEST CONDITIONS

Crosshead Speed :............. 0.1 In/Min
Load Cell Capacity :.......... 5000 Lb
Threshold :................... 5 % Of FSL
Break Criterion :............. 95 %
Extensometer Used :........... 1 1:Y,0:N
Gage Length :................. 1.00 In
Action @ End Of Test :........ 1 1:St,0:Rtn
Crosshead Direction :......... 1 1:Up,0:Dn
Yield(Zero,Offset) :.......... 1.0 1:Z,2:Off
Offset At Yield :............. 0.2 %

TABLE 3. ALUMINUM/GRAPHITE P55 COMPOSITE TENSILE TESTED AT 4.2K

. ADVANCED MATLS. LAB

Concord, MA

Tensile Test

Batch Number: Al COMPOS.4K
Date: 04-11-87 Number of Specimens : 1

Operator I.D. :............... TA
Storage Disk No. :............ 1
Comments :.................... Al 6061+C P55 #G5123

TEST RESULTS

	Thick./Dia In	Width In	Peak Load Lb	U.T.Stngth PSI	Yld Stngth PSI	Yld Elong. %	Brk Stngth PSI	Brk Elong. %	Modulus PSI	Energy Ft-Lb
1	0.045	0.246	945.940	850.727E+02	656.377E+02	0.403	850.727E+02	0.377	217.320E+05	0.177

STATISTICS

Mean	0.045	0.246	945.940	850.727E+02	656.377E+02	0.403	850.727E+02	0.377	217.320E+05	0.177
Min	0.045	0.246	945.940	850.727E+02	656.377E+02	0.403	850.727E+02	0.377	217.320E+05	0.177
Max	0.045	0.246	945.940	850.727E+02	656.377E+02	0.403	850.727E+02	0.377	217.320E+05	0.177
St.Dev	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% C.V.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TEST CONDITIONS

Crosshead Speed :............. 0.1 In/Min
Load Cell Capacity :.......... 5000 Lb
Threshold :................... 5 % Of FSL
Break Criterion :............. 95 %
Extensometer Used :........... 1 1:Y,0:N
Gage Length :................. 1.00 In
Action @ End Of Test :........ 1 1:St,0:Rtn
Crosshead Direction :......... 1 1:Up,0:Dn
Yield(Zero,Offset) :.......... 1.0 1:Z,2:Off
Offset At Yield :............. 0.2 %

SECTION 5

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